

**STUDY OF COMPARATIVE LOCATIONS OF IRON
AND STEEL INDUSTRY IN YUGOSLAVIA**

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I. Spatial Planning of an Industry in Yugoslavia

1. The Yugoslav planning system has been dealing mainly with macroeconomic categories: rate of growth, proportions between various branches of economic activities, especially between so-called part I and part II of the economy, and with the implementation of planned social development goals. Since Yugoslavia is a developing country, many new plants have been constructed and the question of optimum locations of the new plants has arisen. In decided-upon optimum locations, it is necessary to compare several alternative locations in different regions at the different levels of economic development. So, one of the locational criteria (locational factors) for a new plant is dependent upon the level of the economic development of an alternative region. Recently, as a planning method, locational models have been introduced attempting to obey economic criteria in location decisions. Moreover, it does not mean that the principle of even regional development has been given up on. With regard to that principle, the rule of "primus inter-pares" has been applied [1] for underdeveloped regions in locating new plants. In this way, objective quantitative methodology can be done and applied in the process of plan implementation.

Since the Yugoslav economic system is, in essence, a planned market economy on a self-management basis, it is possible to accept the "least costs" approach in space economy analysis.

The consequence is that economic goals in an industry's locational model are usually defined as the minimum transport and locational-dependent production costs. From a practical point of view regarding planning procedure, only this approach can be successfully applied. The other approaches are mainly theoretically important because of difficulties in constructing models in a convenient form for computing processes or foreseeing difficulties in defining functions and parameters (demand levels, price elasticities, etc).

2. There was a lot of criticism in the USSR regarding Weber's individual plant location approach pointing out that basic principles in the socialistic economy regarding the realization of maximal social effects from the point of view of even development of all regions, promotion of underdeveloped areas, etc., and that the main task of an industrial location does not lie in determining the optimal individual location effects, but in its broader social role of realizing plans of economic development [2].

But contemporary analytical tools which are applied in space economy analysis make it possible to define more complex economic goals as, for example, the minimum transport and locational-dependent production costs of a whole industry. So, in the USSR the many locational models are constructed and applied [3] as well as in the US [4] or in other countries .

So, "basic techniques of programming industrial locations gradually acquire their proper place, importance, and role in the theory and practice of the industrial development of the East and West. Methods and problems of individual location are given more emphasis in the corresponding literature of countries with centrally-planned economies. On the other hand, programming of industrial locations has found an important place in the planning of economic development in many countries that clearly have private initiative." [2]

3. Several different methods have been applied for optimum solution computation. Classical Weber's-type problems have been solved by the so-called polivector method. [2] Problems of the territorial gravity-center of electrical energy consumption was solved by this method. The application of this method is simple: a region is put in a system of coordinates. So, we can find values of the abscisa (x) and the ordinate (y) for each consumption location. Mean values of weighted ordinates and abscisas give the ordinate and abscisa of optimum location. Weights are quantities of electrical energy consumption in different places (locations). This method has been used to determine optimum location of a cement plant in Bosnia.

In the more complicated cases with different locational factors, the abridged comparative method [2] has been applied. This method recognizes two kinds of locational factors: measurable and non-measurable. The following are measurable locational factors:

- a. location investment costs--that is, non-recurrent costs, and
- b. production and transport locational costs--that is, recurrent costs.

This idea can be shown in this way:

$$T_i = \sum_{k=1}^K t_{ik} + \sum_{p=1}^P t_{ip} \quad i=1....M$$

Where:

T_i denotes total measurable locational costs upon the location "i";

T_{ik} denotes non-recurrent locational costs of "k" factor on the location "i";

T_{ip} denotes annual recurrent locational costs of production and transport of the "p" factor upon the "i" location.

$i=1....M$ denotes alternative locations;

$k=1....K$ denotes locational factors influencing non-recurrent costs;

$p=1....P$ denotes locational factors that have recurrent influence upon costs of production and transport.

Recurrent costs should be discounted for the life period of the production unit. The result obtained in this way should be corrected by the influence of non-measurable factors that are expressed in a point system. The location with minimum corrected total location costs is the optimal one.

Besides these methods, the other common methods have been applied in Yugoslavia as, for example, the transport problem

of linear programming (cement industry, etc.). If we have more alternative (possible) plant locations, several possible plant locations, several possible raw material locations, and many consumption locations of final product, more sophisticated methods should be applied, as for instance linear programming. Nevertheless, the problem and approach is one of determining the "least cost" as it has already been mentioned.

In the following chapters an illustration of the application of a simple spatial industrial model in iron and steel industries shall be attempted. We emphasize the efficiency aspect of the model with respect to the significance of the relevant locational factors.

II. Regional Consumption and Production of Steel Products

4. Since our task is to analyze the efficiency of spatial* (locational) models of the iron and steel industries, we should address ourselves to the general spatial distribution of consumption and production.

There is a discrepancy between consumption and production of steel products in Yugoslavia, and difference is due to importing. In 1936-8, consumption of steel per capita was 17 kg; 1961, 101 kg, and expected in 1970 to be about 200-240 kg; i.e., about 4,800,000 t. [6.] Consumption could not be such by Yugoslav supply, and importing can be expected.

*In Yugoslavia the term "spatial" model of an industry has been used [1] instead of "locational" model.

TABLE I

Region	Expected Production	Expected Consumption	Difference -000-t
Slovenian	735	803	-68
Middle Croatian	285	769	-474
Bosnian	1040	708	+332
Adriatic Coast	--	575	-575
North Serbian	1000	1597	-597
South-Macedonian & Monte Negro	1269	348	+921
TOTAL	4329	4800	

Many steel factories plan to expand and increase their production if they get enough investing capital. The Table 1 illustrates the regional discrepancy between the expected consumption and production. (Expected production means capacity which will be constructed and capacity wanted to be constructed by factories altogether.) Data of all factories in a region are added and compared with consumption within the specific region. Regions are determined by gravity principle, i.e., the location of consumption belongs to the nearest (the cheapest transport costs) steel production center. So, Montenegro, for example, belongs to the southern (Macedonian) region and its production is added to Macedonian production as well as consumption. These data can be mainly found in [6] as well as the definition of regions. Delineation of Southern region is corrected by gravity principle so that it is larger than in [6].* The Adriatic region is delineated as it gravitates to the Adriatic steel plant in the middle of the region (Zadar).

Final data on production will probably be different from the data in Table 1. So it might be expected to be added an increase of planned (expected) production in Bosnia, Serbia, and a little in Middle Croatia during the next period, so that total supply will meet demand by weight.

5. In spite of the problem regarding the structure of the final product in each plant, and the structure of demand in each region,

*Montenegro is included.

we will suppose that in the long-run, every kind of final product could be produced in any factory at any location. This means that we can use steel as a common unit for capacity of production and consumption. This assumption allows us to construct the general simple model and investigate the influence of the most important locational factors on spatial efficiency. We should take into account the simple fact that the ratio between incoming and out-going materials--i.e., ratio between weight of raw materials and fuel on the one side, and final products on the other side, amounts to 3 or 4:1. This ratio depends upon the quality of iron ore, on the technological process of steel producing (i.e., L.D., or open hearth), and on the preparation of iron ores for smelting and the like.

Finally, the transport rate policy is very important: different transport rates for the raw materials (usually lower) and final products (usually higher) could determine material or market transport locational orientation.

Because of this, we cannot conclude just from Table 1 in which region the production should be increased. The table suggests the conclusion that the location of plants more likely fits the raw material orientation* rule than market orientation. Middle Croatia, North Serbia, and Slovenia represent mainly consuming regions. The Adriatic

*Southern region, except Montenegro and Bosnia, can be recognized as they fit raw material orientation rule.

seashore region should be considered as being market and raw material orientated, if the import of iron ore and coking coal is taken into account. Bosnia (with Sisak in Croatia) could be considered as raw material oriented because its production will be ever more greater than its consumption and it has its own iron ore deposits. Macedonia has similar characteristics as Bosnia has.

So, we can consider production in North Serbia (Smederevo) and Slovenia (Jesenice) as typically market oriented.

III. Locational Factors in Yugoslav Iron and Steel Industry

6. The main locational factor in the iron and steel industry traditionally is iron ore and coking coal. Moreover, technological processes have been improving, and the relative importance of each locational factor has been changing. In so many instances, we can say that the market is the most important locational factor.*

The iron ore is not of a very high grade in Yugoslav mines. The most important mines are: Vares with 91939.000t, A+B class and 34.0% content of iron on the average. Better quality iron ore contains about 39%. Deposits in Ljubija amount to about 105458.000 with 43% iron content on the average. In iron ore mines in Macedonia, there are about 104,228,000 deposits with 34.3% iron content on the average (7). It is not necessary to deal with the other chemical characteristics of iron ore,

*Theoretical consequences are explained in Chapter IV.

and we can accept the general assumption that smelting costs depend upon the content of iron in the iron ore (6) . According to (8) and (7) the costs of production of one ton of pig iron from iron ore in Ljubija with preparation process (and costs) amount to 190.33 din or 2.098 T iron ore per ton of pig iron; costs of coking coal amounts to 216.41 din or 1.068 ton coking coal per ton of pig iron. This calculation is made on the assumption that the steel plants are located at the iron ore deposit sites.

From the locational point of view, it is important to consider whether preparation of low quality iron ore will be performed at the mine or at the blast furnace location. We suppose that Ljubija will deliver 2.098 t iron ore per ton of pig iron to any iron and steel plant at any location. Further, we assume that the other mines will deliver weights that are proportional to their average raw content related to iron ore in Ljubija, i.e., Vares 2.620 tons, Tajmiste (South region--Madedonia) 2.620 tons and imported iron ore 1.650.* The base for this calculation is statistical data of Ljubija, given in (7) and (8) , and general data about iron content of iron ore in Tajmiste and in Vares. Thus, we estimate, in a way, the value of iron ore without the exact cost data.

In spite of the "artificial" character of this calculation, it won't influence the final result of our model because we will deal with the classical transport model in which raw material suppliers

*As it was used in (6)

will deliver all of their production, i.e., supply will be equal to demand. And on this basis we will be able, by means of dual variable, to draw final conclusions about spatial efficiency of the location pattern. It means that the main locational factor will be transport. Differences in costs* between raws will influence only the levels of dual variables in optimum solution and in this way allow estimation of spatial efficiency of locational model.

7. According to (g), in Yugoslavia, steel plants will be constructed with the LD or LDAC process. From the locational point of view, this is important because of relative share of pig iron in the charge of the steel furnace. If we suppose an LD furnace will be constructed, we could take only about 30% pig iron in burden and the rest as scrap. We suppose, according to (7), that there should be produced 770 kg of pig iron per ton of crude steel. So that proportion can be performed by LD or open hearth furnace at any location. The rest of burden of LD or open hearth furnaces will be considered as own or bought steel scrap. In any case, we suppose that steel scrap is a ubiquitous raw material, i.e., locationally unimportant. It can be done because of its small share in total transported material, and equal treatment of each possible location.** Generally, we can express it in this way:

*Differences are constants that will be explained later.

**It will be analyzed in Chapter IV.

$$(1) \quad K = \frac{Q_p}{Q_r} \text{ where}$$

K denotes sharing coefficient of pig iron in produced steel;

Q_p denotes quantity of pig iron

Q_r denotes quantity of produced steel

As it is mentioned, we suppose the same coefficient at each location, i.e., $K = .77$.

Further, we have transport costs of iron ore per ton of produced crude steel as follows:

$$(2) \quad T_{ij}^s = KN_i T_{ij} \text{ where}$$

T_{ij}^s denotes transport costs of iron ore delivered from mine at location "i" to iron and steel plant at location "j" per ton of crude steel;

N_i denotes needed quantity of iron ore delivered from mine at location "i" per ton of pig iron;

K denotes constant .77;

T_{ij} denotes transport costs per ton of iron ore from mine "i" to steel plant at location "j";

8. Coking coal is an important locational factor and we should add its transport costs to the transport costs of iron ore:

$$(3) \quad T_{ij}^u = T_{ij}^s + T_j^c \text{ where}$$

T_j^c denotes transport costs of coking coal per ton of crude steel at steel plant "j" and T_{ij}^s is defined by (2).

Since different kinds of iron ores use different quantities of coke (coking coal) per ton of pig iron, this should be added to the total costs of a production unit, i.e., to one ton of iron ore or crude steel. But, as we will see later, it is equivalent to add a constant value to the transport problem, without changing the optimal solution. Because of that, it does not need to be done.

Further, since coking coal has been imported from the USSR or the USA by ship, it is possible to add to the total transport cost per ton of steel; the transport costs of coking coal from the nearest harbor to the considered location "j", as has been done for imported iron ore. Because of simplicity and insignificance, it is assumed that the same quantity of coal transported from the nearest harbor to the "j" location of iron and steel plant.* Since limestone and electrical energy can be considered from a regional point of view as ubiquitous materials in Yugoslav circumstances, the expression (3) defines transport costs of all inputs of location "j".

TABLE 2

<u>Location</u>	<u>Capacity:</u> <u>-000-t</u>
Ljubija - Bosnia	1690
Vares - Bosnia	1589
Tajmiste - South (Mac.).	1084
Import - Adriatic Seashore	437

*In this case, it is the constant per column.

Capacities are expressed in tons of crude steel, i.e., capacity of iron ore mine "i" = $\frac{1}{.77 N_i}$ so that the total capacity is 4800.000 t. crude steel. This data is based on (6) and expresses the general tendencies of iron ore mines or steel plants (Skopje) expansion.

Import has an analytical importance, i.e., it should be considered comparatively as a new possible locational factor in the spatial aspect of the development of iron and steel industries. The price of imported iron ore, as it is mentioned for costs of production per unit of crude steel, is not explicitly figured. So, locational "advantage" is expressed by the position of a possible plant location in respect to the nearest gravitational port. The restraint is quantity imported. Thus, the aim of this analysis is not to compare the economic efficiency of home iron with imported iron. The implicit assumption is that prices per ton of iron ore are the same and that costs of production depend upon transported iron ore per ton of product. As in (10), one can simply assume that costs of pig iron are formed on the basis of so-called "relative values" of iron ores which can be expressed in the following formula:

$$(4) \quad S = M + v = k \text{ where}$$

- S denotes cost per ton of iron
- M denotes costs of the burden
- v blast furnace operating costs
- k overheads, including capital charge and administrative costs

If S is a constant, the items of unit costs should be able to be substituted. So transport costs of iron ore will vary and depend upon the quality of iron ore and the possible plant's location. Transport costs should be added to the costs of production expressed by (4). On the other hand, it means that we suppose every iron ore can be prepared on an optimum degree of beneficiation and reach the acceptable cost level.* All technical conditions at each location are the same by assumption.

9. The labor force in this industry--as a locational factor--has never been the most important factor. Labor force costs per unit of final product are not high related to costs of raw material, fuel and transport costs (6). So, it can be assumed that the labor force is a ubiquitous locational factor from the regional point of view. It is more important as a micro-locational problem, i.e., if we seek an optimum location in a given region. Generally, we suppose that this problem is solved in the same way at each possible location.** Further, we will suppose that water supply is a negligible locational factor from regional viewpoints, i.e., that is, it is a ubiquitous locational factor, too.

10. Transport is a common locational factor that connects iron mines, steel plants, and markets. Transport costs per ton of final products from the steel plant location to the location of demand (processing or consumption) can be expressed by:

* This explanation is equivalent to that expressed in part 6.

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" f_{jk} " when "j" denotes location of steel plant and "k," location of processing industry. Final demand of steel products and capacities of integrated iron and steel plants and rolling mills can be expressed in weights (tons) of crude steel as well as capacities of iron ore mines. In this way, the homogenous industry model can be constructed.

Finally, in our analysis we suppose that there are no capacity bottlenecks in the railway network. This assumption actually fits the Yugoslav circumstances. The total transport costs per ton of final product can be expressed in this way (according to (1), (2), and (3)):

$$(5) \quad T_{ijk} = t_{ij}^u + f_{jk} = t_{ij}^s + t_j^c + f_{jk} = KN_i t_{ij} + t_j^c + f_{jk}$$

IV. Locational Aspect of Optimum Combination of Production Factors in Iron and Steel Industry

11. Main Characteristics of Technological Process:

Integral iron and steel plants are considered as economical production units with three main production stages:

- production of pig iron,
- production of crude steel, and
- production of final steel products.

The processing industry uses steel products as raw materials (manufacturing fabricating industry, automotive, shipbuilding, steam boiler industry, etc.) and it forms a spatial-scattered demand for them.

Figure 1 presents technological connections of production stages from raw material and fuel to final products (2) . It can

be said that exogenous production factors are: coke, coal, iron ore, limestone, and old scrap (iron, steel). Own steel scrap in rolling mill, coke gas, slag, etc., are secondary products which can be used in technological processes as endogenous production factors. Coke and pig iron are endogenous production factors, also: coke, mainly in pig iron production, and pig iron in crude steel production. Rolling mills use different kinds of inputs, produced in open-hearth furnaces, electric arc furnaces, oxygen furnaces, and produce final steel products for market (plates, hot rolled sheets, cold rolled sheets, tinplate, etc.).

In a stage of production, different technological processes can be used: i.e., open hearth furnaces or the oxygen furnace process in producing steel (crude steel). The application of a specific process depends upon the exogenous factors of production and the economic advantages of a particular process:

- various proportions of scrap and pig iron can be used in the open-hearth process of crude steel production; choice will be made depending upon the relative prices of scrap and pig iron, including transport costs.
- oxygen method of steel production will be chosen depending upon its high productivity and decreasing processing costs that should reward increasing transport costs of iron ore needed for more pig iron used in steel making.

In this analysis we suppose that the choice of the exogenous factors of production is made by coefficient k expressed by (1) and that it is the same for each possible location.

12. Two approaches can be distinguished:

- to minimize individual plant production and transport costs, or simply locational-dependent costs,
- to minimize locational dependent costs of the whole industry.

Individual plant locational costs can be considered as the technological process and locations of exogenous factors of production and markets are given, and optimum location should be sought. It is a classical approach (11) . On the other side, it can be supposed that the possible location of the plant is given, and the optimum combination of exogenous factors of production should be sought. Let us concentrate on the first type of problem where the location is a variable. In this case, the possible combinations of optimum locations depend upon the location and quality of iron ore, coke coal, and upon the locations of demand for the final steel products: (12, 24) :

- 1) If deposits of iron ore and coke coal, as well as the market, are in the same region, the optimum location of the steel plant will be in this region also;
- 2) If coke coal is located in the region of steel products' demand, and high quality of iron ore is in another region, optimum location will be in the region of market and coke coal;
- 3) If deposits of coke coal are in the region of steel product demand, and low quality iron ore is located in another region, the optimum location of a steel plant will be in the iron ore region;
- 4) If the deposits of coke coal and iron ore are in the same region, and the market for steel products is in another, the optimum location will be in the region where the raw materials are to be found;

- 5) If the steel products' market and the deposit of coke coal are in the same region, and if another steel product market is in the region of high quality iron ore, it may be possible to establish the steel plant in both regions;
- 6) If steel products' market and iron ore deposits are in the same region, and deposits of coking coal are in another region, the optimum location would be in the region where the market and deposits of iron ore are;
- 7) If the market of steel products is between two regions, iron ore and coking coal, the optimum location would be in the steel products' market;
- 8) If deposit of coking coal is between the steel market region and the region of iron ore deposits, and if the transport route passes through the location of coking coal, then the optimum location of the steel plant would probably be the region where the coking coal deposits are;
- 9) The last possible combination assumes that in the region of steel products' market there are lots of old steel scrap, and that high quality iron ore deposits are in another region. The optimum location will be in the steel products' market because small quantities of high quality iron ore and small quantities of coking coal need to be transported. These variants define the classical locational problem:

--in each variant proportions of exogenous factors of production are given depending upon their quality;

--capacities of raw materials, and fuel production units are not limited;

--there is just one location of raw materials, "fuel" or a market.

So, the problem is of a "triangle type": iron ore-coke coal-steel market products, in which the region of possible locations is a continuous surface of a triangle or line. The optimum location will always be inside of the triangle or line, and in most cases it will be at one of the vertices of the triangle or line.

If the location of the iron and steel plant is given, the entrepreneur will combine exogenous locational factors of production in a way in which the unit locational-dependent costs will be minimized. It has been assumed that several locations of iron ore deposits, coking coal, were alike with excess capacities.

13. Let us introduce more locations of iron ore deposits, coking coal, old scrap, and markets of final steel products. In these circumstances, we have to solve three problems: optimum capacity, optimum combination of exogenous production factors, and optimum locations, i.e., optimum number of production units (iron and steel plants). If we suppose that capacities of iron ore mines expressed in crude steel are equal to the demand of final steel products, it means that technological process (or proportions of combinations of exogenous production factors) are given.

Further, if previous factors are given, it means that the combination of exogenous factors is the same at each possible iron and steel plant location. The most efficient technological process is implicitly assumed, i.e., from the point of view of the whole iron and steel industry, it is rational to use the same proportion (quantity) of pig iron in burden of steel furnaces at each location.

This assumption follows the general policy in Yugoslavia's iron and steel industries. We are not going to check on this further in this analysis; regardless, it is possible to choose different ratios, expressed by formula (1), for different locations. So, it can be concluded that if the ratio of exogenous production factors (expression (1)) and the capacities of plants and mines are given, the general problem of choosing optimum capacities and optimum combinations has been narrowing down to a problem of optimum

combination of exogenous production factors, or, in other words, to a problem of minimizing the total transport and production costs.*

Dual variables of the optimum solution of the transportation problem will be used in estimating the advantages and disadvantages of each location. Locations with the highest rents can be considered as more efficient from industry's point of view or from the standard point of a defined objective function.

14. Iron and steel plants have been concentrated at one location because of the cost advantages caused by savings in the transport costs, heat energy (gases) and the like. These savings could not be achieved if different stages of the production process were apart on the different locations. Because of that, we assume that there should be an independent iron and steel plant (iron, crude steel, rolling) at each location we are dealing with. Economies of scale define the relationship between unit costs of final products and the capacity of a plant: if capacity of the plant increases, the unit costs decrease until an optimum level is reached. So, capacity of the plant will increase to the minimal total average costs.

Finally, a greater region can be supplied by greater production. Critical boundary will be at points where marginal transport costs are equal to decreasing unit costs (because of expanded capacity) and beyond which added transport costs per unit of product will be greater than savings per unit of products due to increased capacity.

Many factors influence the decreasing of unit costs:

*If capacities of mines and plants are given and demand is equal to supply, it is equivalent to a problem of minimizing transport costs.

**If density of demand is equal in every point of surface.

- capital investment in blast furnaces relatively decreases by increasing capacity; if the volume of the blast furnace is greater, savings of investment in equipment, costs of coke consumption, labor force and maintenance per unit of pig iron are lower; driving rate of coke increases, and coke rate falls as the size of furnace increases, and because of that, unit costs per ton of pig iron decrease;
- investment costs in steel furnace decrease per unit of crude steel by increasing its capacity;
- in the stage of mild rolling investment, costs decrease more rapidly and surface heat losses, fuel consumption rates, etc., come down as size increases;
- costs of handling materials come down by increasing capacities of all stages of production [14] .

15. Let us describe features of our practical problem. Figure 2 presents main features of the locational industrial model we are dealing with. As it has been mentioned, the combination of exogenous production factors at each location is given. This means that the proportion of pig iron and scrap in steel-making in the same technological process are determined. The problem is how to combine exogenous production factors in iron-making because of the possibility of using iron ore, limestone and coking coal from any source (site). In this case, the locational-dependent factor of production, assuming typical blast furnace and disregarding the problem of indivisibility in all stages of integrated production process, can be identified and the locational-dependent costs of production and transport can be computed per ton of pig iron, crude steel, or final products from each possible source of iron ore, limestone and coking coal to the given

*If density of demand is equal in every point of surface

location of the plant. So, the total locational-dependent costs per ton of crude steel or final steel products are included. Endogenous production costs are supposed to be the same at each plant location and are disregarded from a locational point of view. In the steel-making stage of the whole production process, exogenous production factors do not appear (figure 1).

From the standpoint of the processing industry using final steel products, the exogenous costs are transport costs incurred in shipment from any iron and steel plant to any center (location) of steel product consumption. In this way, the locational characteristics of the model are determined.

In Yugoslav circumstances, and according to the aim of this analysis, the model presented in figure 2 can be simplified:

- if limestone is a ubiquitous material, it can be disregarded as a locational negligible because transport costs for each plant location are low and approximately equal;
- if the source of coking coal supply can be defined for each location so that coking coal has been transported from the nearest port, and transport costs added to the unit locational costs of production and transport, it will not appear as a separate restriction in the linear system of equations-restraints. Similarly, it can be done with scrap, if we take into account that metal/scrap ratio is high and the same for each location.*

Finally, according to the figure 2, we have a simple locational model with one factor of production on the input side, and one final product on the output side. Iron ore as an input has several sources (iron mines); crude steel, several plant locations; and processing

*It is defined by formula (1)

industries distributed at many locations of all regions. So, the restraint factors are capacities of iron ore mines, iron and steel plants and of the processing industry. Because of these characteristics, the locational model can be defined in the transport form of linear programming model with objective function being to minimize locational-dependent transport and production costs.

V. Mathematical Formulation of the Spatial Model

16. Let us define the variables and parameters of transport problem of L.P. in table form [15, 16]:

TABLE 3

a_i , $i = 1 \dots R$, denotes capacities of iron ore mines at locations $1 \dots R$;

b_j , $j = 1 \dots K$, denotes capacities of iron and steel plants at locations $1 \dots K$;

a_{R+K} , $R+K = 1 \dots R+K$, denotes capacities of iron and steel plants as suppliers of final steel products at locations $1 \dots K$;

b_{K+1} , $K+1 = 1 \dots K+L$, denotes capacities of processing industry at locations $1 \dots L$;

c_{rk} , $r=1 \dots R$, $k = 1 \dots K$, denotes unit transport production cost defined by expression (3);

c_{R+K} , $K+1$ denotes unit transport costs of final products from iron and steel plants to the locations of the processing industry. It is an element f_{jk} in expression (5);

v_k , v_{K+1} , u_r and u_{R+K} denote dual variables;

M denotes prohibitive transport costs so that the shipments from origin to prohibitive part of the table 3 can not be realized.

Diagonal elements in the left block of final product suppliers $(C_R + k, K)$ more "connections" between raw material-steel plant locations and steel plants-processing industry (final consumption) locations. The general mathematical form of this model is:

$$(5) \quad \text{Min} T = \sum_{r=1}^R \sum_{k=1}^K C_{rk} + \sum_{k=1}^K \sum_{l=1}^L C_{R+k,l} X_{R+k,l}$$

with restraints

$$(6) \quad \sum_{k=1}^K X_{rk} = a_r \quad r = 1, \dots, R$$

$$(7) \quad \sum_{r=1}^R X_{rk} = \sum_{l=1}^L X_{R+k,l} = b_k = a_r + k, \quad k = 1, \dots, K$$

$$(8) \quad \sum_{k=1}^K X_{R+k,l} = b_l \quad l = 1, \dots, L$$

$$(9) \quad X_{rk} \geq 0, \quad X_{R+k,l} \geq 0$$

In more complex instances restraints (6) and (7) would have sign " \leq " and elements " $C_{R+k,k}$ " wouldn't be prohibitive. In this model $C_{R+k,k} = M$, because of restraint (7). So, this model can be divided into two independent models: the optimum solution of the complex form of the model is equivalent to optimum solutions of the two simple models. The optimum solutions of raw material steel plant block can be computed independently as well as the optimum solution of the final product of suppliers-processing industries. If dual variables are interpreted and transformed into rents and prices at different locations, as it has been shown in [3, 4, 5, 16, 17, 18, 19] optimal price conditions for shipment

24 (a)
- TABLE 3 -

	v_j	$v_1 \dots v_k \dots v_K$	$v_{K+1} \dots v_{K+1} \dots v_{K+L}$
u_i	u_i	$b_1 \dots b_r \dots b_K$	$b_{K+1} \dots b_{K+1} \dots b_{K+L}$
u_1	a_1	$c_{11} \dots c_{1k} \dots c_{1K}$	$M \dots M \dots M$
.	.	.	.
.	.	.	.
.	.	.	.
u_r	a_r	$c_{r1} \dots c_{rk} \dots c_{rK}$	$M \dots M \dots M$
.	.	.	.
.	.	.	.
.	.	.	.
u_R	a_R	$c_{R1} \dots c_{Rk} \dots c_{RK}$	$M \dots M \dots M$
u_{R+1}	a_{R+1}	$c_{R+1,1} \dots M \dots M$	$c_{R+1,K+1} \dots c_{R+1,K+1} \dots c_{R+1,K+L}$
.	.	.	.
.	.	.	.
.	.	.	.
u_{R+k}	a_{R+k}	$M \dots c_{R+k,K} \dots M$	$c_{R+k,K+1} \dots c_{R+k,K+1} \dots c_{R+k,K+L}$
.	.	.	.
.	.	.	.
.	.	.	.
u_{R+K}	a_{R+K}	$M \dots M \dots **$	$c_{R+K,K+1} \dots c_{R+K,K+1} \dots c_{R+K,K+L}$

**** $c_{R+K,K}$ (no room above)**

of final products at a location of processing industry can be expressed in this way:

$$(10) \quad W_{K+1} \leq C_{rk} + C_{R+K+1} + r_r + r_{R+K} \text{ and if} \\ X_{R+K+1} > 0$$

$$(11) \quad W_{K+1} = C_{R+K+1} + W_k + r_{R+K}$$

where W_{K+1} denotes delivered equilibrium price at the location $K+1$ that consists from:

unit costs of raw material with transport costs per ton (crude steel), transport costs of final products, rent of raw material supplier and rent of final product supplier.

Rents are created by differences in transport costs and production costs on the one side, and capacity restraints on the other side:

--if the capacity of a mine (iron ore) is greater than the total shipments (supplier with idle capacity)* in the optimum solution, it has zero rent; the same is valuable for suppliers of final products;

--if the capacity is fully utilized, the supplier (of raw material or the final product) will have non-negative rent, [17, 16]. As there are no idle capacities in our model, greater rent indicates better location and zero rent indicates the most expensive, marginal suppliers. Rents will indicate what locations have advantages for expanding on the long-run** expanding capacity for a unit would decrease transport (and production) costs in the amount of rent per product unit; if rent covers costs of capacity expansion, investment can be performed. If demand has been increasing proportionally at every location, the most efficient expansion of capacities will be at the location of the supplier with the highest rent.

So, the system of rents will show the points of rational expansion on the material and final product side, demand is given and is equal

$$* \sum_r X_{rk} < a_r$$

** Transport problem can be used for long-run analysis in this case because rents indicate locational advantages for efficient expansion, ceteris paribus.

to supply. Correction could be effected by decreasing costs incurred by the economy of scale: at the most efficient location the decrease due to the rent and the economy of scale is the highest one. Let us express it in this way:

$$(12) \quad D_t = d_r + d_s$$

where

D_t denotes total unit costs decrease that consist from:

d_r unit costs decrease caused by locational rent, and

d_s unit costs decrease due to economy of scale.

Supposing a proportional regional growth of final product demand, we have a very simple analytical tool to estimate the locational advantages of suppliers in the growing process, ceteris paribus.

In the model described by equations (5) - (9) and (10) - (11) formula (12) can be transformed into:

$$(13) \quad C^R + k = D_t^R + k - w_k$$

where $C^R + k$ denotes difference between total decrease of unit costs due to locational rent and economy of scale (formula 12) and delivered price of raw material from the iron ore mines to the iron and steel production units in the optimum solution. Obviously the biggest difference means the most advantageous location.

The formal procedure of including savings in costs due to economies of scale, if the optimum solution is given, means subtraction of a constant in a row of a transport problem without changing the optimum solution. In terms of dual variables

(rents) it is equivalent to the increase of locational rent for the same constant. In expression (12) d_s represents this constant. So, D_t^{R+k} denotes locational rent corrected by the economy of scale.*

17. From tables 1 and 2 it follows that $\sum_{r=1}^4 a_r = 4800\ 000$ tons, $\sum_{k=1}^{63} b_k + 1 = 4800\ 000$ tons. The total supply of final products

is equal to total demand as it can be understood from restraints (7), $\sum_{k=1}^6 a_{r+k} = \sum_{k=1}^6 b_k = 4800\ 000$ tons.

Transport costs, i.e., elements of transport matrice c_{rk} and $c_{R+k, K+1}$ are computed from existing transport rates from about 1968. Computing procedure was explained in Chapter III. Optimum solution of the model described in this chapter, with data analyzed in previous chapters and this passage, will be analyzed in the next chapters.

VI. Pricing and Spatial Efficiency

18. From the society's point of view, rational spatial distribution of iron and steel plants would be achieved when the total costs of production and transport are minimized for the given demand. In the pure competition, market prices will be minimized, and the social optimum set up on the long-run.

Linear model, introduced in the previous chapter, describes pure competition in the short-run: demand and capacities of suppliers

* See attached page for footnote

** (footnote)

Let us recall that optimum condition in the classical transport

problem is $u_i + v_j \leq c_{ij}$ or in terms of rents $c_{ij} + r_i \geq w_j$,

where $r_i = -u_i$ and $w_j = v_j$. If we subtract the same constant k on each side of the first equation, we have $u_i - k + v_j \leq c_{ij} - k$ and conditions are unchanged, but $r_i = -u_i + k$.

are given. Optimal price system is defined by expressions (10) and (11), and locational advantages by expression (12). The question is: will the theoretical optimal conditions of spatial allocation be followed by development, and what price policy can be expected if spatial rationalization will have to follow the existing spatial characteristics of development? Finally, are differences between locations related significantly enough to rents and economies of scale?

19. Let us discuss the theoretical alternatives of possible price policies which are set up by individual firms providing a homogenous product. If a producer is the monopolist, it can apply mill pricing, uniform pricing, or impose a price discrimination policy so as to maximize its own profit. The mill pricing system means the same price will be established for all customers at the plant location; uniform pricing means the same price shall be set for all customers at their locations; discriminatory pricing means that customers who are closer will pay a higher price at mill location than customers who are further away, and both of them will pay transport costs. The most efficient policy, from the firm's point of view, is the discriminatory policy.

The choice of a policy depends upon the degree of monopolization, on the degree of government intervention, and on the kind of production (how much transport costs are relevant). For practical purposes possible price policies of a collusive oligopoly are more interesting (17) :

- a) The entire market is divided into fixed market areas of the firms. This system often brings about inefficient spatial allocation of resources, i.e., demand is met by more expensive production: not every firm operates at the optimum scale, and the least expensive producer cannot expand his production. Uniform minimum mill price system has similar consequences.
- b) The basing point or "Pittsburgh plus" system had been prevalent in the U.S. for a long time, protecting producers of steel products in Pittsburgh [21, 22, 23]. Basing point system means that consumers will pay the same price in their locations regardless of the producer from whom they buy their products. The delivered price for every producer is the equal base price (of the producer in the base joint), plus transport costs from base point to consumer. Any number of sellers will quote the same price to each buyer independently from their own costs of production and transport. Mill net price for basing point will be the same and independent of consumer location. For all other non-basing point sellers, net mill price will be below or over the basing point for net mill price.

If transport costs are lower from a producer to the buyer than from the basing point producer to that buyer, it will be so called "phantom freight" [23]; if transport costs are higher than basing point, it will be damaged by the so-called "freight absorption." It is clear that the spatial efficiency of this system depends upon which producer (location) is announced as the basing point producer.

The multiple basing point system has more than one basing point, and base price. A "plenary" basing point system announces each mill location as a basing point, and it is the same as if the mill had not established a basing point [23].

20. On the long run, the main question of efficiency is "free entry" supposing the capital is not a scarce factor. In the "free entry" conditions, the final solution would be an optimal spatial allocation of resources related to economy of scale, transport costs with costs of production and prices. Prices would cover production and transport

costs with average "profit" and locational rent only on the competitive level. Locational rent can arise due to long distances when savings in economies of scale are not able to substitute for the increasing transport costs. In the short-run, rent can arise due to the restraints of capacities and differences in production and transport costs. If higher quality resources have to be used on the long-run, rents will be assigned to better quality resources and the delivered price at any location of demand in the competitive economy, as it is defined by our model, is the same for any supplier. Price covers all costs of the most expensive supplier and all costs with rent of the other less expensive suppliers. Differences between optimum prices (according to optimum solution) of this model and single basing point system, is in determining delivery prices: are they the result of pure competition or are they determined in advance by an oligopoly policy? If the basing point producer is the result of the protection of a more expensive supplier, better locations cannot be used because there is no difference between delivered prices inspite of the possibility to earn rents. Due to oligopolistic policy, increasing capacities on the more convenient location will not occur on the long run.

VII. Significance of the Optimum Solution

21. Figure 3 presents the main results of the model: distribution of the market among different producers located in defined regions, providing a homogenous product. Due to capacity restrictions of

the iron and steel plants, regions IV and VI are exporters, and regions II and V are mainly importers of final products. Importation of region I and III is negligible. The most important question is what can be said about the efficiency of this spatial arrangement. Table 4 presents rents per unit of final products of each supplier, and the price of raw material paid by each producer of final products to suppliers of raw materials. As it has been defined in the preceding chapters, price contains only locational-dependent costs and locational rents. Rents show how much could total unit cost of whole industry decrease if capacity at the considered location increases one unit, provided there is the possibility of a continuous increase or decrease of the capacities. Rents are corrected by the influence of raw material costs, which contain rent of ore mines, too.

Disregarding the economies of scale, specialization and raw material costs, the most competitive region is the Adriatic seashore (III), and the least competitive region is the South (VI, column 2). Including raw material costs, the advantageous and the most disadvantageous locations are the same (column 5). Columns 4 and 5 are constructed using the general rule given in formula (11), of the necessity to cover all costs at a delivered location "K + 1" where the price:

$$W_{K+1} = C_{R+k, K+1} + W_k + r_{R+k}$$

So, the possibility of competitiveness is in r_{R+k} and W_k : greater r_{R+k} and less W_k means greater competitiveness. It does not mean that W_k should be covered by r_{R+k} . Column 4 and 5 show only relative

TABLE 4*

Supplying Region	Locational Rent Per Unit of Production	Paid Price of Raw Material Per Unit of Production	Rank of Advantages	Trans-formed Rank of Advantages
1	$r_R + k$ 2	w_k 3	$r_R + k - w_k$ 4	Min ($r_R + k - w_k$) = 0 5
I	85	121	-36	127
II	95	89	-6	157
III	96	66	30	193
IV	45	66	-21	142
V	44	178	-134	29
VI	0	163	-163	0

*Figures are in dinars (\$1.00 = 12.5 dinars)

TABLE 5*

Supplying Region	$D_t^{R+k} = d_r + d_s$	$C^{R+k} = D_t^{R+k} - w_k$	C^{R+k} after increase of capacity for 3000.000 t
1	2	3	4
I	365	244	269
II	95	6	231
III	296	230	280
IV	335	269	269
V	334	156	152
VI	290	127	127

*Figures are in dinars (\$100 = 12.5 dinars)

positions of region V and VI are significantly worse than other regions.

22. If we still suppose there is homogenous production and demand, and consider influence of the economies of scale on unit costs with respect to existing capacities,* according to our definition in chapter 2, table 1 using expression (13), we have the result as it has been shown in table 5 (see page 32a). It should be stressed that the influence of the economies of scale on unit costs are approximate, and that a capacity of one million tons is considered as an optimum size. The question is what optimum size is and at what region of the unit is cost function decrease of the costs still significant enough? According to (14), the influence of economies of scale can be significant until the size of 2.5 million tons is reached. The problem is how the unit cost curve "looks" following the increase of size and how it depends upon technological processes and types of final products, etc. But, we can conclude that influences of economies of scale, until a capacity of one million tons, is strong enough to change rank list of total advantages (columns 3 and 4, table 5) assuming "flat" unit cost curve after one million tons (7) the same spatial structure of demand, and that the optimum shipment pattern on the increased level would not redistribute added capacity** on other locations.

* only exception in region III

**It would be easy to repeat calculation and allocation added capacity according to optimum solution of an open transport model with fictitious column.

Because of the significance of the influence of economies of scale on unit costs and on improving the relative position of the producer's location, interest in greater investment of all producers can be easily understood.

23. As it can be seen in table 4, "marginal process" is region VI, i.e., the most expensive production comes from this region. Prices at demand locations are on the level limited by the marginal producer (supplier). By market mechanisms or computations, in our case, producers having locational advantages related to "marginal supplier" earn rent, pure, or are corrected by the influence of the economies of scale. If we exclude region II as quantitatively insignificant,* region VI is a marginal supplier including influence of the economies of scale, too. It means that this region can be generally considered as a limiting one. According to the expression of (4) and (11), this region could improve its position saving in raw material costs and in this way be able to decrease price W_k . Its location with respect to the market (shipments even into region II) will force it to seek advantages belonging to its raw material orientation, if such advantages do exist. In spite of the convenient location of raw materials, this region will pay relatively high prices to raw material suppliers, partially assuming use of imported** iron ore or any other iron ore from either region (Bosnia).

* and in reality, highly specialized on the optimum level

**Due to aggregation done in table 1, this region uses, according to optimum solution, imported iron ore which contains high rent as well as its own.

On the other side, due to the high degree of isolation from other regions, it can establish a spatial monopolistic price policy with respect to its raw material supplier and decrease this price, assuming that this price really contains locational rent r_r (expression 10)) and uncompetitiveness of this raw material supplier in the other regions. The rents of raw material suppliers contained in price W_k are the result of "competition" and of the scarcity of higher quality iron ore, and their locational position in respect to iron and steel plants. Granted assumptions from Chapter III, the "marginal process" illustrated by the iron ore mines in Vares (due to relatively lower quality iron ore), and its rent is equal to zero. Delivered price* W_k is the same of each raw material supplier at a given iron and steel plant location.

The economic significance of this "marginal process" is in keeping with delivered prices on the highest level and in "assigning" rents to the better locations or to the higher quality raw materials.

The point is, for instance, will any other raw material supplier with higher costs become the limiting (marginal) one? If it happens, all prices of raw materials can increase. Prices can be kept on the same level only by subsidizing marginal supplier, i.e., by paying him negative rent to cover the loss incurred as a result of the increased costs, and given delivered prices. This can be done from the outside of our economic system defined by the linear model. The same can be applied to the producers of final products in relation to their market.

*Let us recall that W_k is the cost of raw materials (locational-dependent) per unit of final product.

24. Finally, let us discuss the possibilities of future price policy with respect to the equilibrium prices given by the optimum solution. Supposing there is "free entry" in the market, the most competitive new product can emerge and cut rents with regard to the others in region III because this region earns the highest rent. The emergence of this new producer depends upon the rent that has to be able to cover extra capital charges related to the expansion of the existing producers or has to substitute for costs of decreased production at the other locations.

Due to non-optimal capacities and possible savings in costs due to the size increase, a kind of collusive oligopolistic behavior can be expected following the individual interests of producers. It could be done by spatially dividing the market, or by specialization in production of final products.

A spatially-divided market could emerge if the product is homogeneous. In this case, the rational distribution of the market could be accomplished by an optimum solution as it has been in our model. So, it is clear that the existing spatial pattern of producers in respect to consumers and iron ore mines wouldn't be the result of "free entry" in a theoretical sense, not due, at least, to sub-optimal capacities. The division of the market would incur higher costs of production until demand in each market came below the optimum size of the plant.

Final products in the iron and steel industry are pretty heterogeneous, and it is much more realistic to expect a division of types of products which have to be produced at each location (producer). If we consider regional differences with respect to demand of different final products, the location of supplier or the kind of products produced by each producer becomes important. Supposing that there is a concentration of demand for one type of product in a region--it is clear that this region has to be supplied by the most efficient supplier from industry's point of view. As, for instance, a shipbuilding industry is located in region III, it is important to consider from which region this industry will import final steel products. If it would have to import (e.g., from region VI) differences in locational rent and even the economies of scale show a degree of economic inefficiency* regarding this kind of market division. So, specialization of production is not a sufficient condition for spatial rationalization, despite the relatively improving position of the producer benefiting by the influence of the economies of scale. After division of the market, producers can establish a monopolistic price policy. The final result of this analysis is that a more or less efficient spatial pattern of the iron and steel industry means that there will be lower or higher delivered prices and different types of collusive oligopolistic behavior, i.e., sub-optimal spatial allocation of

* See table 4, 5, and figure 3.

resources and the necessity of economic intervention from outside the industry. Planning procedure and economic policy, therefore, should take into account the spatial dimension regarding development of this industry, as it has similarly found out in other studies from other aspects, or in the other social environments {6, 7, 8, 21, 22, 23} .

25. Our analysis belongs to the classical locational approach extended by application of the complex transport model of linear programming. Dual variable analysis has been a useful analytical tool in estimating the real and possible relationships between different regions.

The special emphasis was given to the existing tendencies in capacity expansion, regardless of how much these tendencies are formally or officially determined or accepted. The main problem is to note the influence these tendencies have upon the economic efficiency of the iron and steel industry.

In this analysis, the same technological process has been implicitly supposed at each location. In other words, we suppose that each technological process is possible at each location and we do not consider it as the locational factor from industry's point of view.

On the other side, the technological process becomes a locational factor if we consider a given location and capacities

as given parameters, and have to minimize unit costs with respect to raw material transport costs. The best example to illustrate this is the possibility of choice of the optimum proportion of pig iron and scrap in charge (burden) of open hearth furnaces, in respect to their prices. The LD process offers much less of this possibility for substitution of raw materials relevant from a transport costs point of view. Therefore, benefits from higher productivity of furnaces have to compensate for the higher transportation costs of raw materials.

So, we can distinguish from an individual and an industrial approach.* If we suppose we have large regions in which each producer can utilize all of the benefits from the economies of scale, and benefit from the technological process chosen to minimize unit costs, then industry's optimum combination of exogenous factors of production will be equivalent to the sum of individual optima--assuming there is no quantity restraints of raw materials.

Thus, we can conclude that in existing circumstances, the choice of the technological process can be considered as a locational factor, i.e., as the means for improving locational advantages (region I). But, from industry's point of view, the combination of the exogenous factors of production (expression (1)) can be given in a way to maximize the technological utilization of available scarce iron ore and the like, so that it is possible to minimize only locational-dependent costs of production in a strict sense, as it has been done in this model.

* See Chapter IV

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